Development of an α-particle and TOF ion detector for precise measurements of atomic mass of super-heavy nuclei

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Overview

We have developed a combined TOF and α-particle detector for precise mass measurements of super heavy nuclei. The purpose of the combined detector is to time-correlate the decay energy of targeted radioactive isotopes with their TOF mass measurement, in order to discriminate from background events.

To characterize the detector TOF and decay energy measurements were performed using a combined α-source of ^{244}Cm, ^{241}Am and ^{237}Np, which demonstrated a strong correlation with TOF signal and α particle decay energy.

An α-TOF detector has been installed on a multi-reflection TOF-MS at RIKEN's RI-Beam Factory, and is ultimately intended for mass measurement of very low yield (1 event per day) super-heavy α-emitting nuclei.

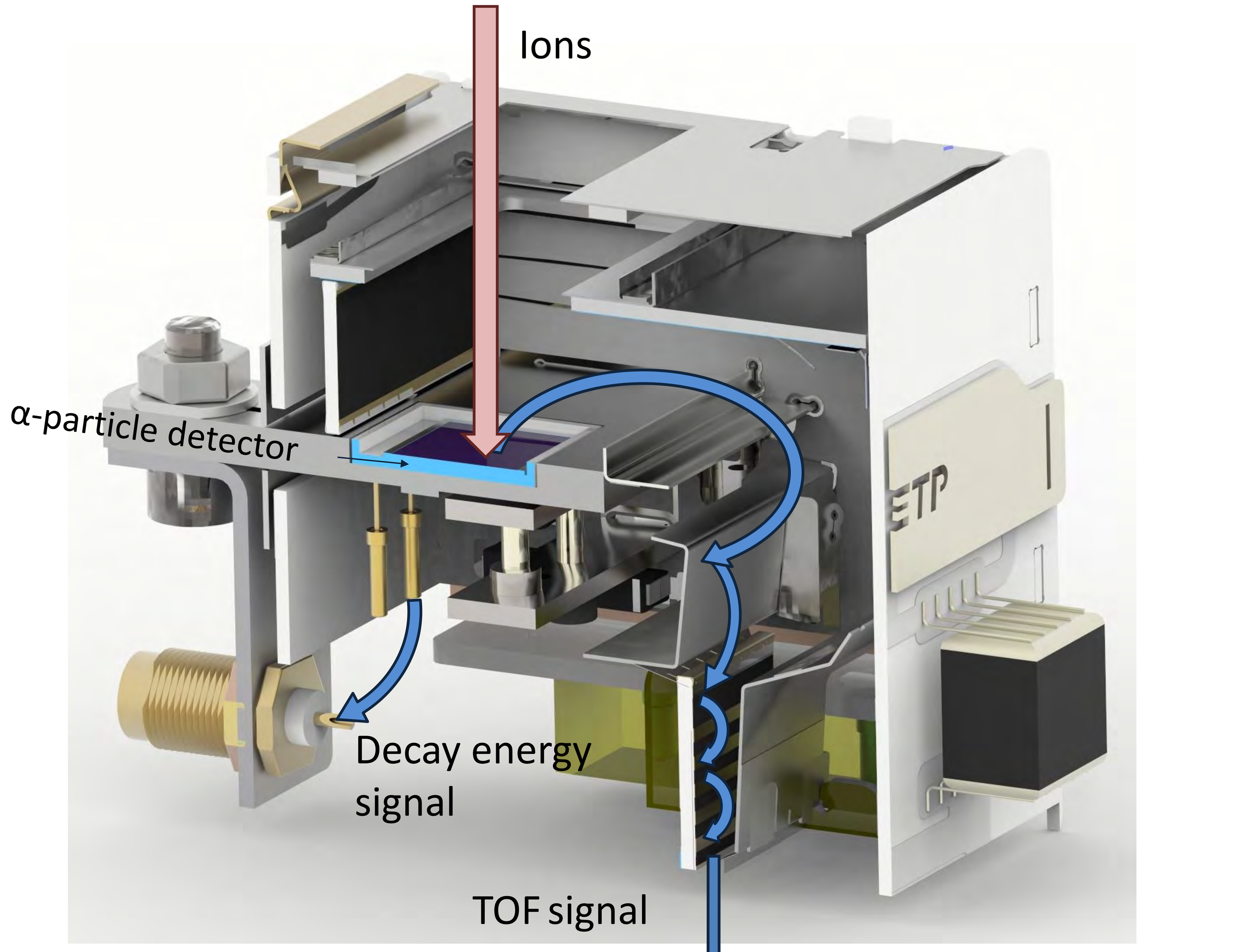


Figure 1.
Cross-section of α-TOF detector. Two signals are extracted from this detector and correlated with one another to discriminate between false-positive and true events. The decay energy signal verifies a TOF signal is real, and the TOF signal is used for mass measurement

Design

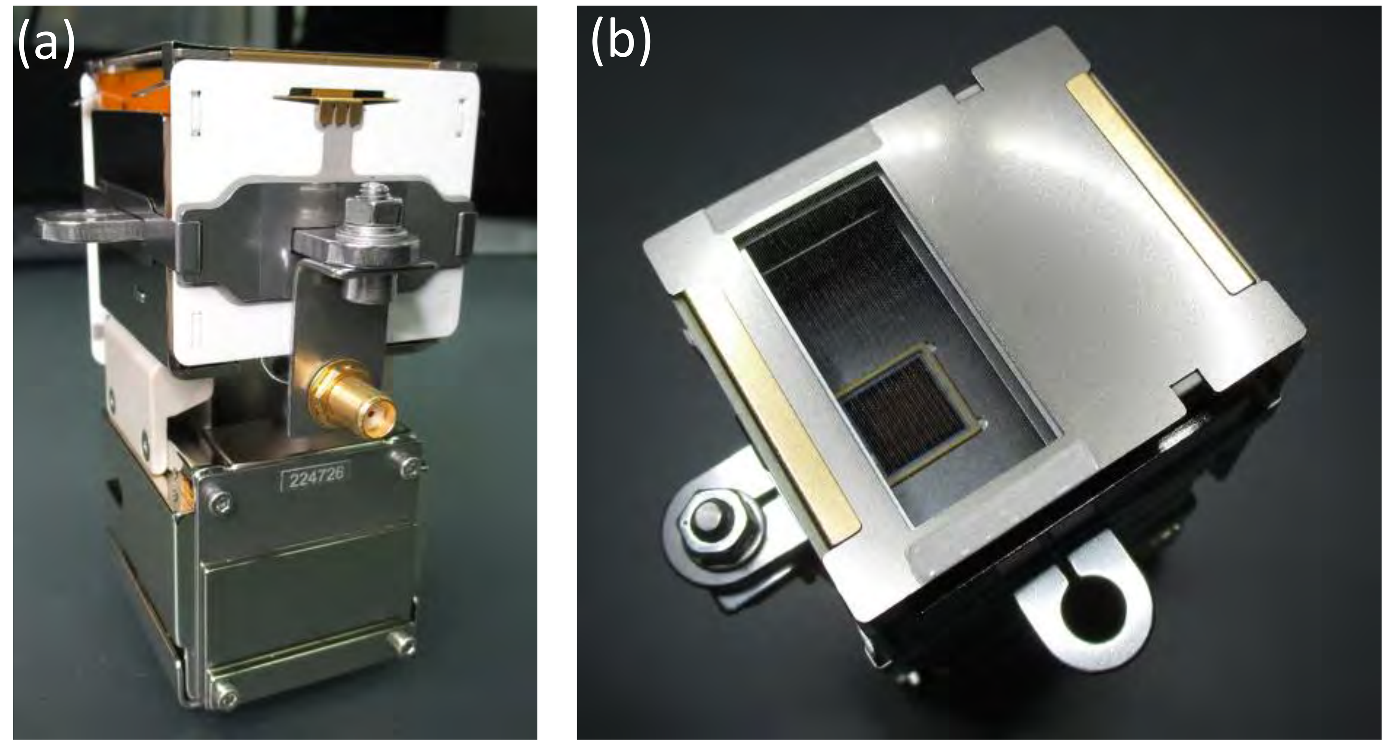


Figure 2.
Photographs of the α-TOF detector. a) shows the SMA output for the Si-SSD. b) shows the Si-SSD in the impact plate, through the ion entrance aperture of the MagneTOF

A silicon-based, solid state, α-particle detector (SSD) was embedded into the impact plate of a MagneTOF Plus ion detector, as shown in Figure 1. The α-particle signal was taken out through the base of the impact plate to an SMA connector mounted onto a tab of the impact plate. To prevent significant electrostatic field variations, the top side of the Si detector was floated to the impact plate voltage (-HV), via the shield of the SMA connector.

The α-particle detector was coated in a thin emissive film to enhance secondary electron generation upon ion impact.

Unstable ions that strike the α particle detector embed themselves within the detector, generating secondary electrons at the surface as they enter the material. The secondary electrons are collected by the crossed electric and magnetic fields of the MagneTOF detector, and transferred to an electron multiplication plate. This very-fast pulse of electrons is collected and forms the TOF signal for the ion arrival. Subsequent α decay of the unstable ion inside the α-particle detector generates a voltage on the detector signal corresponding to the decay energy.

Both the α decay energy, and ion flight time are fingerprints of the specific isomers, and can be correlated to discriminate between true events and false-positives such as neutral molecule noise or electrical noise.

Results

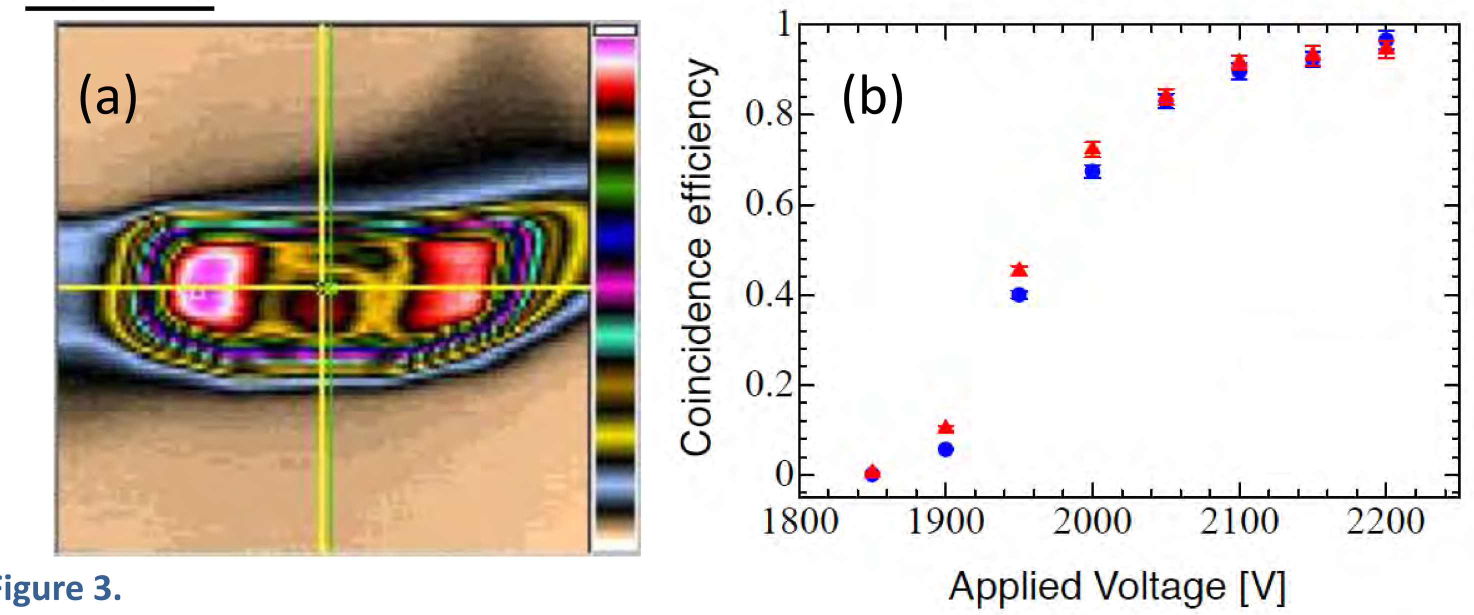


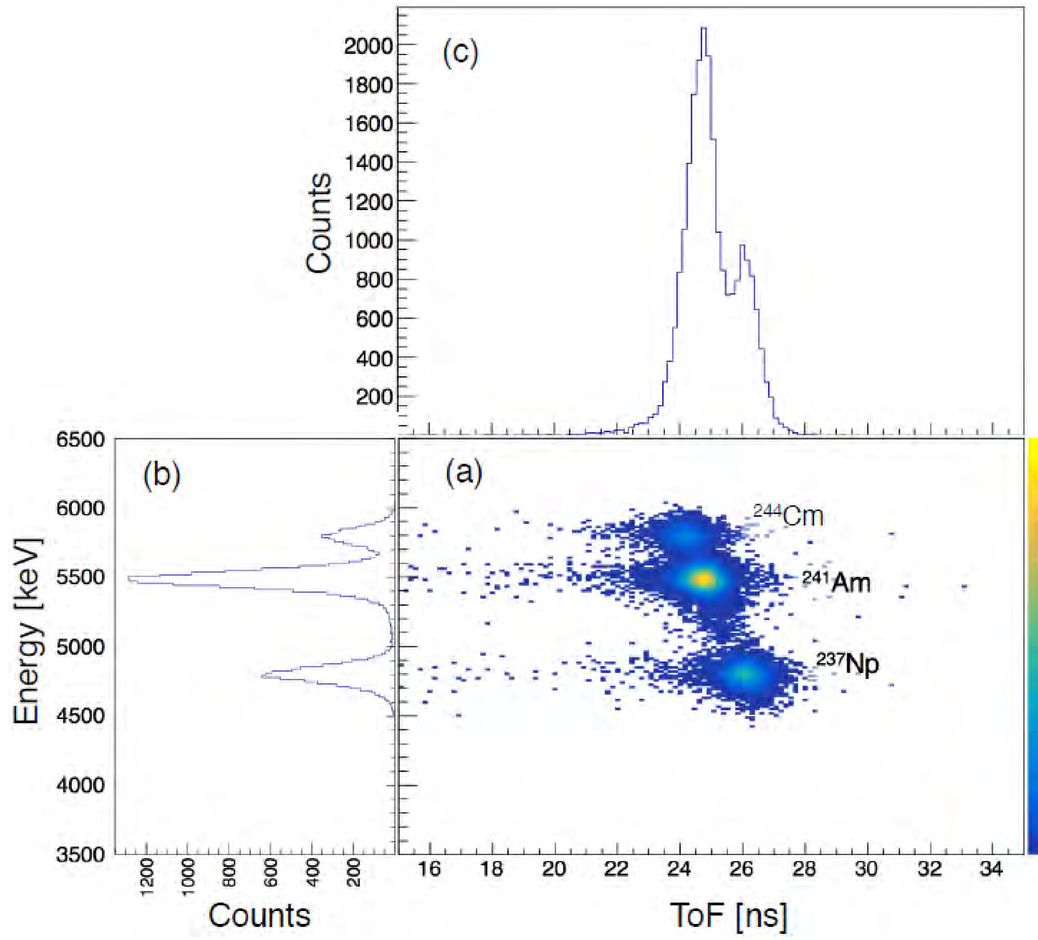
Figure 3.
a) A signal intensity map of the α-TOF aperture. The lower intensity in the center is the SSD location. A diagram of the ion impact plate. b) coincidence efficiency as a function of MagneTOF detector voltage

The combined α-particle and TOF detector was tested at ETP for gain, noise and pulse. Figure 3.a) shows an intensity map of the MagneTOF input aperture, collected by scanning an ion beam (generated by EI of air) across the aperture while measuring the detector output. The central region of the aperture, where the SSD sits, exhibits a slightly lower gain. This is due to a lower secondary electron yield from the SSD than from the impact plate. Other than this variation, the detector exhibited typical MagneTOF performance. Figure 3.b) shows signal coincidence ratio of the TOF detector to the SSD. This was performed at KEK by irradiating the α-TOF detector with 5.48 MeV α-rays from an ^{241}Am source, for which the SSD should have a detection efficiency close to unity. A TOF signal of the 5.48 MeV α particle was considered 'true' if the signal from both detectors occurred within 500 ns of one another, and if the amplitude of the SSD signal was commensurate with the expected particle energy. The arrival rate of α-particles was on the order of 0.1 s^{-1}. MagneTOF operating voltages greater than 2100 V (~5x10^6 gain), achieved correlation efficiencies greater than 90%.

In order to demonstrate the alpha-TOF's intended ability to correlate an α-particle energy with an ion arrival event, a mixed source of α-particles was used: ^{244}Cm (5.8 MeV); ^{241}Am (5.48 MeV); and ^{237}Np (4.89 MeV). Figure 4. a) shows the result of these measurements – an intensity map of the α decay energy vs α-particle arrival time in which the intensity represents the number of coincident counts.

Figure 4. b) shows the projection of the intensity onto the vertical axis (decay energy, keV), while Figure 4. c) shows the number of counts as a function of alpha-particle flight time (ns). The TOF detector is unable to resolve the arrival times of the α-particles, however they can be resolved in the energy domain. This separation of events based on decay energy allows a precise arrival time to be assigned to each, due to the time-correlation of the event

Figure 5.
a) Intensity map of alpha decay energy vs. α-particle arrival time. This 2D plot demonstrates the energy and TOF correlation that can be used to identify 'true' events.
b) α-particle arrival counts as a function of alpha decay energy. The energy resolution is ~141 keV.
c) α-particle arrival counts vs. arrival time.



Conclusion

We have successfully developed and characterized a combined solid-state α-particle detector with time-of-flight ion detector (MagneTOF) to reliably perform mass measurements of super-heavy elements, with very low arrival rates. This α-TOF detector will be used at RIKEN for precise mass measurements of rare, short-lived, super-heavy elements such as moscovium and nihonium.

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